

# Kinetics of Epoxidized Oleic Acid Derived from Palm Oil by *in situ* Generated Performic Acid

M. J. Jalil,<sup>a\*</sup> M. S. M. Zaini,<sup>b</sup> A. F. M. Yamin,<sup>a</sup> S. H. Chang,<sup>a</sup>  
N. Mora,<sup>c</sup> and A. Hadi<sup>a</sup>

<sup>a</sup> Faculty of Chemical Engineering, Universiti Teknologi MARA (UiTM) Pulau Pinang, 13 500 Permatang Pauh, Pulau Pinang, Malaysia

<sup>b</sup> Faculty of Chemical Engineering, Universiti Teknologi MARA Cawangan Terengganu, Kampus Bukit Besi, 23 200 Dungun, Terengganu, Malaysia

<sup>c</sup> School of Technology Industry, Universiti Sains, Malaysia

This work is licensed under a Creative Commons Attribution 4.0 International License



## Abstract

Epoxidized palm oleic acid is often regarded as a highly valuable oleochemical due to its wide range of industrial applications, including cosmetics, personal care, and pharmaceutical products. In this study, oleic acid derived from palm oil with iodine value of 98.99 g/100 g, containing 75 % of oleic acid, 12 % of linoleic acid, 6.5 % of palmitic acid, and 6.5 % of stearic acid was epoxidised by *in situ* generated performic acid with hydrogen peroxide as oxygen donor and formic acid as active oxygen carrier in the presence of catalytic amount of inorganic acid. The rate constant for epoxidation of oleic acid was found to be  $1.133 \cdot 10^{-3} \text{ mol}^{-1} \text{ s}^{-1}$  and activation energy was  $91.12 \text{ kJ mol}^{-1}$  at temperature of  $75 \text{ }^\circ\text{C}$ . In addition, thermodynamic parameters such as enthalpy, entropy, and free energy of activation were  $88.2 \text{ kJ mol}^{-1}$ ,  $-67.90 \text{ J mol}^{-1} \text{ K}^{-1}$ , and  $88.36 \text{ kJ mol}^{-1}$ , respectively. Relative conversion data showed that it was possible to develop epoxides from locally available, natural, renewable resources such as palm oil.

## Keywords

Epoxidation, palm oil, kinetic study, activation energy, oxirane

## Introduction

The chemical derived from oils and fats of vegetables, also called oleochemical, represents one of the cheaper and highly available petroleum-derived products. Efforts in finding potential sustainable and renewable resources have gained interest as the concerns over environmental issues, such as global warming and climate change, are in the limelight. In general, fatty acids have different levels of saturation. Fatty acids, such as linoleic acid, contain three double bonds, while oleic acid has only one double bond. Therefore, they are categorized as unsaturated fatty acids. Regarding the composition of fatty acids in crude palm oil (CPO), it can be observed that palmitic acid constitutes the largest percentage of fatty acid composition, followed by oleic acid with values of 44 %, and 39.2 %, respectively. Owing to the high percentage of double-bond fatty acids in CPO, the modifications of these fatty acids play a key role in the production of marketable products in the manufacturing industry.<sup>2</sup> Therefore, it has been widely used in lotions and soaps to nourish the skin. Oleic acids contain high lipid content among all fatty acids. As a result, the benefits of these fatty acids can be harnessed to produce good quality skincare products. Despite the potential benefits offered by oleic acids, these fatty acids are often been neglected and regarded as by-products of low value.<sup>3</sup> Although there are numerous studies regarding the potential benefits of epoxidized oleic acids, fewer studies have focused on the kinetics of epoxidized oleic acids. In an *in situ*

epoxidation process, the peracid forms within the same medium and the fatty acids are epoxidized simultaneously with the *in situ* formed peracid. This makes kinetics studies on the overall reaction rather complex and challenging. There are various ways in which the kinetic reactions of epoxidized fatty acids could be examined and they can be classified based on the epoxidation process, epoxidation reagent, catalyst, and solvent. Epoxidized oleic acid with an almost complete conversion of unsaturated carbon chains and negligible ring opening can be synthesized via *in situ* techniques. The chemistry underlying the *in situ* epoxidation process consists of two main reactions (*i.e.*, peracid formation and epoxidation), as given by Eqs. 1 and 2:

Peracid formation:



Epoxidation:



The kinetics of *in situ* epoxidation of oleic acid by reacting hydrogen peroxide with acetic acid, in which sulphuric acid is used as catalyst, revealed that the formation of peracetic or performic acid is integral in determining the rate of the overall reaction.<sup>5</sup> Rangarajan *et al.*<sup>6</sup> examined the kinetic parameters for *in situ* epoxidation of soybean oil by peracid, whereby sulphuric acid was used as catalyst. It shall be noted, however, that the epoxidation process

\* Corresponding author: Mohd Jumain Jalil, Master of Chem. Eng.  
Email: [jumain.jalil@gmail.com](mailto:jumain.jalil@gmail.com)

was treated as a two-phase system in their study and found each reaction rate by looking at different phases. The pioneer kinetics study on oleic acid epoxidation was conducted by *Chou and Chang*.<sup>7</sup> Their study revolved around the role of acetic acid as an oxygen carrier in two phases (oil and aqueous) epoxidation of oleic acid. They described the kinetics of oleic acid epoxidation with peracid to be independent of oleic acid concentration, but highly dependent on the mixing rate and the rate of reaction of acetic acid. They obtained the rate constant for the epoxidation as  $k = 4.96 \times 10^{-4} \text{ mol}^{-1} \text{ s}^{-1}$  at the temperature of 35 °C. *Campanella et al.*<sup>8</sup> examined that the epoxidation process can be adequately described using an (equilibrated) two-phase reaction model. The model accounts for both the reversible peracid formation (in the aqueous phase) and the epoxidation reaction together with the attacks on the epoxide ring by formic acid and performic acid (in the organic phase). For both forward and reverse reactions of performic acid formation, the reaction rate constants were calculated as  $9.16 \times 10^{-6} \text{ mol}^{-1} \text{ s}^{-1}$  and  $1.25 \times 10^{-5} \text{ mol}^{-1} \text{ s}^{-1}$ , respectively. Consequently, the reaction rate of epoxidation process is  $7.83 \text{ mol s}^{-1}$ . It can be observed from the existing literature that most of the previous studies have focused on achieving the highest conversion of carbon double bonds (C=C) in the fatty acids to oxirane rings. It can also be observed that the development of kinetic models for the epoxidation process is ongoing due to the high demand for epoxidized oleic acids. The present study, however, focuses on the epoxidation of fatty acid-oleic acid, a smaller molecule compared to a triglyceride molecule. Thus, the objective of this study was to investigate the epoxidation of oleic acid derived from palm oil with respect to the relative content of oxirane and iodine value, and kinetics model of epoxidized oleic acid derived from palm oil.

## 2 Materials and methods

### 2.1 Materials

Oleic acid-based palm oil in this study was obtained from Quality Reagent Chemical (QReC) from the Republic of New Zealand as a raw material. Formic acid, hydrogen peroxide, and sulphuric acid were also obtained from QReC.

### 2.2 Experimental set-up

Initially, 100 g of oleic acid were mixed with a specific molar ratio of formic acid to oleic acid (0.5 : 1.5) in a 500 ml three-neck, round-bottom flask, which was equipped with a magnetic stirrer, thermometer, and reflux condenser immersed in the thermostatic oil bath. The mixture was then stirred at variation of stirring speed (50–300 rpm), and heated to desired temperature (35–95 °C). Next, 0.5 g of catalyst (sulphuric acid, nitric acid, and hydrochloric acid) were added to the mixture, followed by dropwise addition of hydrogen peroxide ( $\varphi = 30\%$ ) for a molar ratio of hydrogen peroxide to oleic acids. The sample was retrieved every 5 min to determine the oxirane (epoxide) oxygen content, which was then used for the calculation of relative conversion of double bond to oxirane,  $RCO\%$ .

### 2.3 Analytical procedure

Based on the repetitive gas chromatography analyses done by Chung Chemical Sd. Bhd, Malaysia, palm fatty acids contain 75 % of oleic acid, 12 % of linoleic acid, 6.5 % of palmitic acid, and 6.5 % of stearic acid. The experimentally determined oxirane oxygen content ( $OO_{\text{exp}}$ ) value in the epoxidized oleic acids was determined by direct titration using hydrobromic acid solution in glacial acetic acid, according to AOCS Tentative Method Cd 9-57,<sup>9</sup> as shown in Eq. (3):

$$OO_{\text{exp}} (\%) = 1.6 \times N \times (V-B) / W \quad (3)$$

where  $N$  is the normality of HBr,  $V$  is the volume of HBr solution used for blank (in ml),  $B$  is the volume of HBr solution used for titration (in ml), and  $W$  is the weight of sample (in g). The iodine value ( $IV$ ) of oleic acids used, which indicates the degree of unsaturation in the oleic acids, was calculated based on AOCS Standard Method Cd 1d-92, as in Eq. (4):

$$IV (\text{g I}_2 / 100 \text{ g sample}) = (B-S) \times N \times 12.69 / \text{mass of palm oil} \quad (4)$$

where  $B$  is the volume of titrant for blank run (in ml),  $S$  is the volume of titrant for sample (in ml), and  $N$  is the normality of sodium thiosulphate. The iodine value was then applied to calculate theoretical oxirane oxygen content ( $OO_{\text{theo}}$ ),<sup>9</sup> by the following Eq. (5):

$$OO_{\text{theo}} = (IV_o A / 2AI) / (250 + (IV_o A / 2AI) A_o) \times A_o \times 100 \quad (5)$$

where  $IV_o$  is initial iodine value,  $A_o$  is the molar mass of oxygen, and  $AI$  is the molar mass of iodine. Then, the percentage of relative conversion to oxirane was calculated using Eq. (6):

$$RCO\% = OO_{\text{exp}} / OO_{\text{theo}} \times 100\% \quad (6)$$

### 2.3 Kinetics study

The kinetics data obtained were represented by a kinetics model based on a modified reaction scheme, whereby two assumptions were made:<sup>15</sup>

The rate of the reaction mechanism (peracid formation) was considered as the rate-determining step, thus peracid formation is a slow-step reaction and epoxidation a fast-step reaction. Therefore, the overall reaction rate depends on peracid formation.

The peracid concentration is constant throughout the reaction.

According to *Gan et al.*,<sup>10</sup> the rate of epoxidation can be expressed as:

$$\frac{d[\text{EpOA}]}{dt} = k ([\text{H}_2\text{O}_2] - [\text{EpOA}])([\text{RCOOH}]_0) \quad (7)$$

where EpOA is the epoxidized oleic acid, and the subscript 'o' is the initial concentration.

## 2.4 Thermodynamic analysis of oleic acid epoxidation

The activation energy can be calculated through Arrhenius equation<sup>10</sup>

$$k = Ae^{-E_a/RT} \quad (8)$$

where  $k$  is the rate constant, and  $T$  is the temperature.

The enthalpy of activation  $\Delta H$  is calculated using the following equation:

$$\Delta H = E_a - RT \quad (9)$$

where  $E_a$  is the activation energy determined from the Arrhenius plot,  $T$  is the absolute temperature at the optimum condition, and  $R$  is the universal gas constant.

The entropy of activation  $\Delta S$  is given by:

$$k = \frac{RT}{Nh} e^{\Delta S/R} e^{-E/RT} \quad (10)$$

and the free energy of activation  $\Delta G$  is given by:

$$\Delta G = \Delta H - T\Delta S \quad (11)$$

where  $k$  is the rate constant,  $R$  is gas constant ( $R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$ ),  $T$  is absolute temperature,  $N$  is Avogadro constant ( $N_A = 6.02 \cdot 10^{23} \text{ mol}^{-1}$ ), and  $h$  is Planck's constant ( $h = 6.62607015 \cdot 10^{-34} \text{ J s}$ ).

## 3 Results and discussion

### 3.1 Epoxidation of oleic acid-based palm oil

The iodine value analysis provides an insight into the reactivity and the degree of unsaturation of fatty acids. The iodine value (IV) is a measure of the number of double bonds, and oxirane value is an indication of the percentage content of epoxide group.<sup>11</sup> The quality of the epoxidized oil can be regarded as good if the oxirane value is high and the iodine value low. The higher the iodine value contributes to higher reactivity and lower stability of the fatty acid. The maximum conversion of oleic acids to oxirane was improved to 85.6 % by applying the optimum operating conditions. From a theoretical viewpoint, high iodine value indicates that the probability for the iodide ions to attach to the unsaturated carbon chains is higher. The analysis showed that the tendency for iodide ion to attach to oleic acid structure was four times higher than the epoxidized oleic acid, meaning that there were less unsaturation sites available in the former structure. The analysis clearly suggested that most of the available unsaturated double (C=C) bonds in the crude oleic acid had been broken and converted into an oxirane ring structure. Fig. 1 shows that iodine value decreases *per unit time* with increasing the relative conversion of oxirane. This phenomenon was similar in previous reports, indicating the reduction of unsaturated fatty acid due to the formation of epoxy group.<sup>12,13</sup>

### 3.2 Epoxidation kinetics

Chemical kinetics refers to the rate of reaction and the factors that affect this speed. Therefore, the efforts aimed at optimizing the rate constant that would enhance the yield

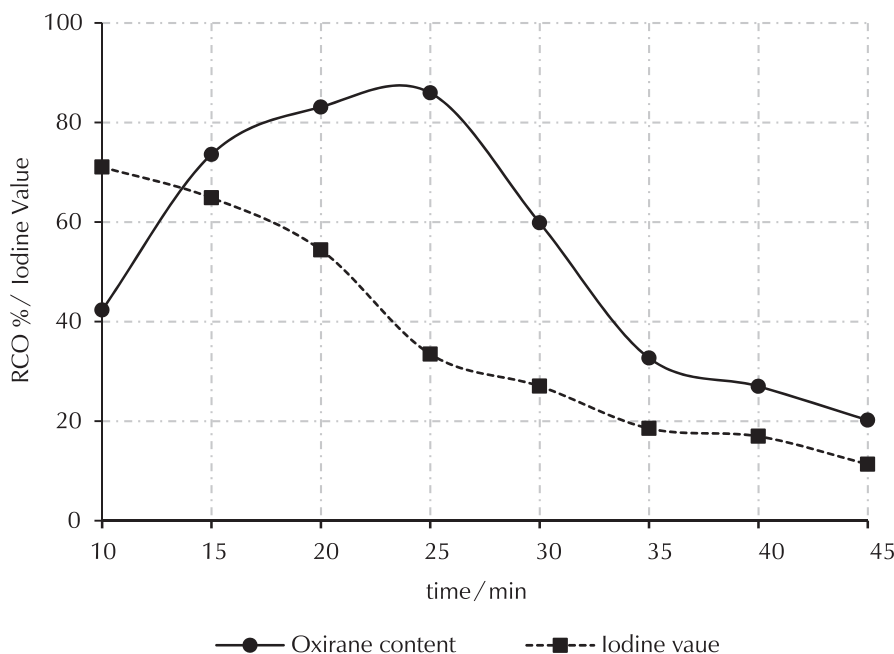


Fig. 1 – Iodine value vs. oxirane content

maximally. Determination of the rate constant value is essential in determining the value of any reaction by applying the reaction rate equation. In the industrial applications of kinetics, knowledge of chemical rate equation is essential in establishing the optimum conditions of temperature, pressure, feed composition, and space velocity. Activation energy can be confirmed as the most important property in any kinetically controlled chemical reaction. No matter how strong the collision between correctly oriented reactants, if there is not enough energy possessed by them to overcome the activation reactant, no transformation from reactant to product will occur at transition state.<sup>16</sup> Epoxidized oleic acid with almost complete conversion of the unsaturated carbon and negligible ring opening can be synthesized by the *in situ* techniques described.<sup>17</sup> Eq. 7 can be re-written in natural logarithm form as follows:

$$d([EpOA] / ([H_2O_2] - [EpOA])) = k [RCOOH]_0 dt \quad (12)$$

$$\int_0^{EpOA} \frac{1}{([H_2O_2] - [EpOA])} = \int (k [RCOOH]_0) dt \quad (13)$$

$$\ln ([H_2O_2] - [EpOA]) - ([H_2O_2]_0 - [0]) = k [RCOOH]_0 t \quad (14)$$

$$\ln ([H_2O_2] - [EpOA]) - \ln([H_2O_2]_0 - [0]) = k [RCOOH]_0 t - 0 \quad (15)$$

$$\ln ([H_2O_2] - [EpOA]) = k [RCOOH]_0 t + \ln[H_2O_2]_0 \quad (16)$$

Then,  $\ln\{[H_2O_2] - [EpOA]\}$  vs. reaction time ( $t$ ) based on (14) was plotted at different temperatures, as shown in Fig. 2. The deviations from linearity were considered to occur due to the rate constants obtained from the initial linear portions of the plots.<sup>7</sup>

Table 1 – Rate constant of epoxidation of oleic acid estimated at various reaction temperatures

Temperature /°C	Oxirane oxygen content	Rate constant ( $k$ ), $10^{-4} / \text{mol}^{-1} \text{s}^{-1}$
55	1.0950	0.1213
75	1.6065	0.1133
95	1.3950	4.9200

The rate constant obtained for *in situ* epoxidation of oleic acid palm kernel oil by performic acid is good enough and comparable with other values reported by previous study on soybean oil and rubber seed oil, as shown in Table 2. It is evident from the data presented in Table 2 that the apparent activation energy is different for different vegetable oils. This might be attributed to several factors, which include the variations of fatty acid composition in the oils, epoxidation reaction conditions, as well as the chemical structure of the oils. According to Jalil et al.,<sup>3</sup> the rate of reaction may increase, decrease, fluctuate or remain constant with increasing temperature. In addition, the value of the rate constant depends highly on temperature and the type of vegetable oil. The rate constants will increase as temperature increases up to a certain point, and then the rate constant will decrease again.

Activation energy can be confirmed as the most important property in any kinetically controlled chemical reaction. The value of  $R^2$  (0.7059) in this linear model shows that the model is regarded as an accurate model. The experimental

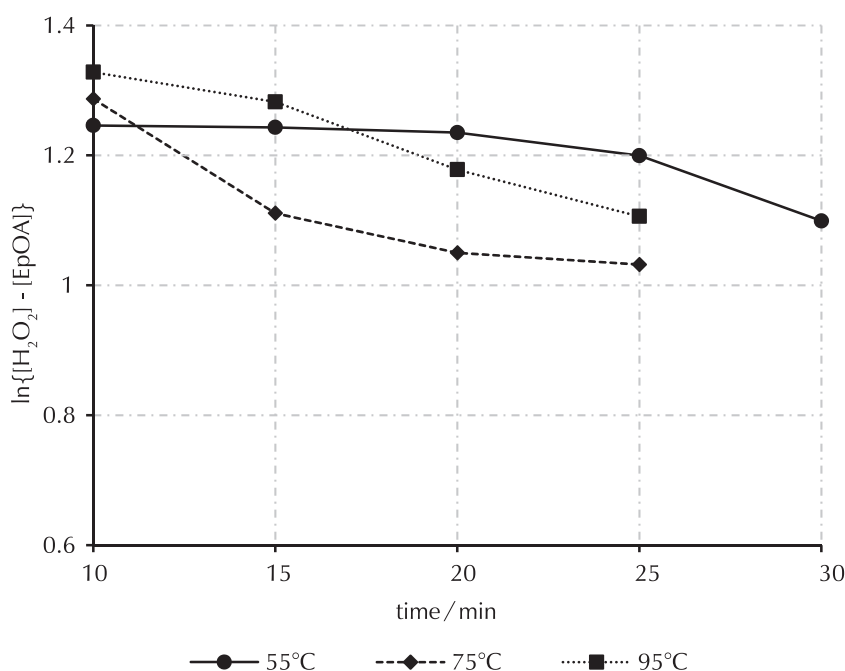


Fig. 2 – Plot of  $\ln\{[H_2O_2] - [EpOA]\}$  vs. reaction time (min) for epoxidation of oleic acid

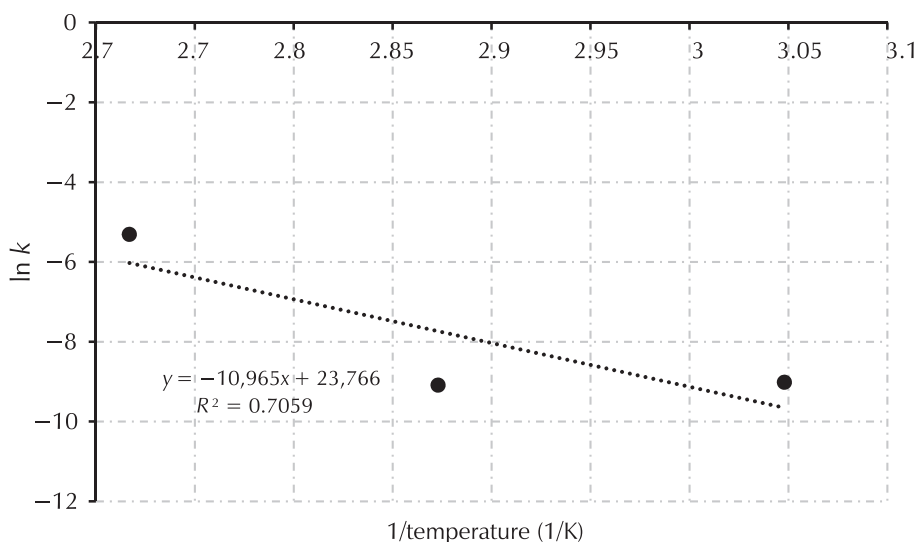


Fig. 3 – Activation energy,  $E_a$  for epoxidation of oleic acid by performic acid

Table 2 – Thermodynamic parameters for epoxidation of oils<sup>18</sup>

Oil	Thermodynamic parameters			
	$E_a$ / kJ mol <sup>-1</sup>	$\Delta H$ / kJ mol <sup>-1</sup>	$\Delta S$ / J mol <sup>-1</sup> K <sup>-1</sup>	$\Delta G$ / kJ mol <sup>-1</sup>
soybean oil	44.85	42.09	-200.07	108.7
sunflower oil	82.88	80.16	-74.2	104.52
rapeseed oil	25.86	23.10	-217.5	95.31
fatty acid methyl ester	32.21	28.95	-201.5	97.32
oleic acid derived from PO*	91.27	88.2	-67.9	88.36

\*Determined based on experiments at optimum conditions in this study

data were fitted into linear regression of Arrhenius model, as depicted in Fig. 2, to determine the activation energy,  $E_a$  of epoxidation of oleic acid. Based on the linear regression of Arrhenius equation, the activation energy value was 91.27 kJ mol<sup>-1</sup>.

The calculated values of  $\Delta S$  and  $\Delta G$  were -67.9 J mol<sup>-1</sup> K<sup>-1</sup> and 88.36 kJ mol<sup>-1</sup>, respectively. The results indicated that the present reaction was endothermic in nature, since the enthalpy of activation was positive, hence an increase in the reaction temperature led to an increase in conversion of oxirane. Entropy was also calculated in order to measure the randomness of the particles in a thermodynamic system. The negative value of entropy indicates that the particle has less disorder, higher reaction rate, and less reaction time to achieve maximum yield of epoxide. In addition, the free energy of activation was found to be positive, indicating that the reaction was non-spontaneous under the present experimental conditions<sup>19</sup>, and therefore, external energy was needed to induce the reaction. As temperature increases, the non-spontaneity of reaction would increase,

which results in free energy activation value to be positive. Hence, at any particular time, the yield of oxirane will increase.

## Conclusion

The kinetics of the *in situ* epoxidation process was examined in homogeneous (single-phase) system. The rate constant of reaction,  $k$ , at various reaction temperatures was determined. It was found that the kinetic parameters vary with temperature, which is highly beneficial for scale-up production of epoxidized oleic acid using the *in situ* technique. Based on the rate constants obtained, the activation energy ( $E_a$ ) and pre-exponential factor ( $A$ ) were calculated 21.78 kcal mol<sup>-1</sup> and 2.0, respectively. Furthermore, thermodynamic analysis conducted on the epoxidation-derived oleic acid indicated that the reaction was endothermic in nature and non-spontaneous.

## List of abbreviations

- CPO – crude palm oil  
 RCO% – relative conversion of double bond to oxirane  
 $OO_{\text{exp}}$  – experimentally determined oxirane oxygen content  
 $OO_{\text{theo}}$  – theoretical oxirane oxygen content  
 IV – iodine value

## References

### Literatura

1. A. L. Villa De P, F. Taborda A, C. Montes De Correa, Kinetics of limonene epoxidation by hydrogen peroxide on PW-Amberlite, *J. Mol. Catal. A Chem.* **185** (1-2) (2002) 269–277, doi: [https://doi.org/10.1016/S1381-1169\(02\)00077-8](https://doi.org/10.1016/S1381-1169(02)00077-8).
2. M. J. Jalil, I. S. Azmi, A. R. M. Daud, An Overview of Epoxidation of Vegetable Oils with Peracid- Reaction Mechanism, *Recent Innov. Chem. Eng.* **10** (1) (2017) 1–8, doi: <https://doi.org/10.2174/2405520410666170614113317>.
3. M. J. Jalil, S. K. Jamaludin, I. S. Azmi, A. R. M. Daud, Characterisation of Epoxidation of Palm Kernel Oil based on Crude Oleic Acid, *Industrial Combustion* (2017) 1–9, Article No. 201606, url: [http://www.industrial.combustion.ifrf.net/paper\\_download.html?paperId=147](http://www.industrial.combustion.ifrf.net/paper_download.html?paperId=147).
4. M. J. Jalil, S. K. Jamaludin, A. R. M. Daud, Degradation Oxirane Ring Kinetics of Epoxidized Palm Kernel Oil-Based Crude Oleic Acid, *Chem. Chem. Technol.* **12** (3) (2018) 296–299.
5. M. R. Janković, S. V. Sinadinović-Fišer, O. M. Govedarica, Kinetics of the epoxidation of castor oil with peracetic acid formed *in situ* in the presence of an ion-exchange resin, *Ind. Eng. Chem. Res.* **53** (2014) 9357–9364, doi: <https://doi.org/10.1021/ie500876a>.
6. B. Rangarajan, A. Havey, E. A. Grulke, P. D. Culnan, Kinetic Parameters of a Two-Phase Model for *in situ* Epoxidation of Soybean Oil, *J. Am. Oil Chem. Soc.* **72** (10) (1995) 1161–1169, doi: <https://doi.org/10.1007/BF02540983>.
7. T. Chou, J. Chang, Acetic Acid as an Oxygen Carrier Between Two Phases for Epoxidation of Oleic Acid, *Chem. Eng. Comm.* **41** (1986) 253–256, doi: <https://doi.org/10.1080/00986448608911722>.
8. A. Campanella, C. Fontanini, M. A. Baltanás, High yield epoxidation of fatty acid methyl esters with performic acid generated *in situ*, *Chem. Eng. J.* **144** (3) (2008) 466–475, doi: <https://doi.org/10.1016/j.cej.2008.07.016>.
9. M. Z. Mohd Yunus, S. K. Jamaludin, S. F. Abd. Karim, A. Abd Gani, A. Sauki, Catalytic Efficiency of Titanium Dioxide ( $\text{TiO}_2$ ) and Zeolite ZSM-5 Catalysts in the *in-situ* Epoxidation of Palm Olein, *I.O.P. Conference Series Mater. Sci.* (2018), doi: <https://doi.org/10.1088/1757-899X/358/1/012070>.
10. L. H. Gan, S. H. Goh, K. S. Ooi, Kinetic Studies of Epoxidation and Oxirane Cleavage of Palm Olein Methyl Esters, *J. Am. Oil Chem. Soc.* **69** (4) (1992) 347–351, doi: <https://doi.org/10.1007/BF02636065>.
11. R. A. El-Adly, A. M. Shoaib, Optimum Operating Conditions for Epoxidation Reaction of Jojoba and Castor Oils, *Int. J. Eng. Res. Appl.* **4** (3) (2014) 816–822, url: [http://www.ijera.com/papers/Vol4\\_issue3/Version%201/E14301816822.pdf](http://www.ijera.com/papers/Vol4_issue3/Version%201/E14301816822.pdf).
12. F. E. Okieimen, O. I. Bakare, C. O. Okieimen, Studies on the epoxidation of rubber seed oil, *Ind. Crops Prod.* **15** (2) (2002) 139–144, doi: [https://doi.org/10.1016/S0926-6690\(01\)00104-2](https://doi.org/10.1016/S0926-6690(01)00104-2).
13. M. N. F. Fong, J. Salimon, Epoxidation of Palm Kernel Oil Fatty Acids, *J. Sci. Technol.* **4** (2) (2012) 87–98, url: <http://penerbit.uthm.edu.my/ojs/index.php/JST/article/view/605/397>.
14. N. Mohamed, M. J. Jalil, S. K. Jamaludin, A. R. M. Daud, Formation of Dihydroxystearic Acid from Hydrolysis of Palm Kernel Oil Based Epoxidized Oleic Acid, *J. Appl. Sci. Agric.* **9** (11) (2014) 86–92, url: [www.aensiweb.com/JASA](http://www.aensiweb.com/JASA) (accessed March 1, 2018).
15. M. Musik, E. Milchert, Selective epoxidation of sesame oil with peracetic acid, *Mol. Catal.* **433** (2017) 170–174, doi: <https://doi.org/10.1016/j.mcat.2017.02.012>.
16. P. Saithai, J. Lecomte, E. Dubreucq, V. Tanrattanakul, Effects of different epoxidation methods of soybean oil on the characteristics of acrylated epoxidized soybean oil-co-poly (methyl methacrylate) copolymer, *EXPRESS Polym. Lett.* **7** (11) (2013) 910–924, doi: <https://doi.org/10.3144/expresspolymlett.2013.89>.
17. M. J. Jalil, N. Mohamed, S. K. Jamaludin, A. M. Som, A. R. M. Daud, Epoxidation of Palm Kernel Oil-based Crude Oleic Acid, *Adv. Mater. Res.* **906** (2014) 125–130, doi: <https://doi.org/10.4028/www.scientific.net/AMR.906.125>.
18. T. I. Cooney, F. Cardona, T. Tran-Cong, Kinetics of *In Situ* Epoxidation of Hemp Oil under Heterogenous Reaction Conditions: An Overview With Preliminary Results, in: *eddB2011: 1<sup>st</sup> International Postgraduate Conference on Engineering, Designing and Developing the Built Environment for Sustainable Wellbeing*, 27–29 Apr 2011, Brisbane, Australia, p.p. 106–111, url: <http://eprints.usq.edu.au/id/eprint/19247>.
19. K. Saremi, T. Tabarsa, A. Shakeri, A. Babanalbandi, Epoxidation of Soybean Oil, *Annals Biol. Res.* **3** (9) (2012) 4254–4258, url: <https://www.scholarsresearchlibrary.com/articles/epoxidation-of-soybean-oil.pdf>.

## SAŽETAK

Kinetika epoksidirane oleinske kiseline dobivene iz palmina ulja  
*in situ* proizvedenom permravljom kiselinomMohd Jumain Jalil,<sup>a</sup> Mohd Saufi Md Zaini,<sup>b</sup> Aliff Farhan Mohd Yamin,<sup>a</sup>  
Siu Hua Chang,<sup>a</sup> Norhashimah Mora<sup>c</sup> i Abdul Hadi<sup>a</sup>

Epoksidirana palmina oleinska kiselina često se smatra vrlo vrijednom oleokemijskom tvari zbog širokog raspona industrijskih primjena, uključujući kozmetiku, osobnu njegu i farmaceutske proizvode. U ovoj studiji, oleinska kiselina potekla iz palmina ulja s jodnim brojem 98,99 g/100 g, koja sadrži 75 % oleinske kiseline, 12 % linoleinske kiseline, 6,5 % palmitinske kiseline i 6,5 % stearinske kiseline, epoksidizirana je *in situ* proizvedenom performičnom kiselinom s vodikovim peroksidom kao donorom kisika i mravljom kiselinom kao aktivnim nosačem kisika u prisutnosti katalitičke količine anorganske kiseline. Konstanta brzine za epoksidaciju oleinske kiseline bila je  $1,133 \cdot 10^{-3} \text{ mol}^{-1} \text{ s}^{-1}$ , a energija aktivacije  $91,12 \text{ kJ mol}^{-1}$  pri temperaturi  $75 \text{ }^\circ\text{C}$ . Termodinamički parametri kao što su entalpija, entropija i slobodna energija aktivacije iznosili su  $88,2 \text{ kJ mol}^{-1}$ ,  $-67,90 \text{ J mol}^{-1} \text{ K}^{-1}$ , odnosno  $88,36 \text{ kJ mol}^{-1}$ . Relativni podatci konverzije pokazali su da je moguće razviti epokside iz lokalnih, prirodnih i obnovljivih izvora kao što je palmino ulje.

## Ključne riječi

Epoksidacija, palmino ulje, kinetička studija, energija aktivacije, oksiran

<sup>a</sup> Faculty of Chemical Engineering, Universiti  
Teknologi MARA (UiTM) Pulau Pinang, 13 500  
Permatang Pauh, Pulau Pinang, Malezija

<sup>b</sup> Faculty of Chemical Engineering, Universiti  
Teknologi MARA Cawangan Terengganu,  
Kampus Bukit Besi, 23 200 Dungun,  
Terengganu, Malezija

<sup>c</sup> School of Technology Industry, Universiti Sains,  
Malezija

Izvorni znanstveni rad  
Prispjelo 3. rujna 2018.  
Prihvaćeno 29. studenoga 2018.